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PIC — A Graphics Language for Typesetting
User Manual†

Brian W. Kernighan

Revised, May, 1991

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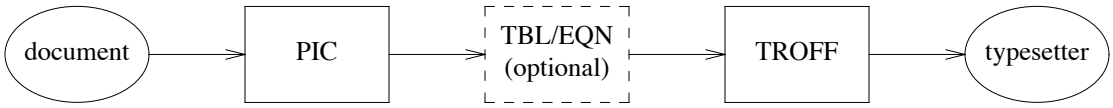
ABSTRACT

Pic is a language for drawing simple figures on a typesetter. The basic objects in *pic* are boxes, circles, ellipses, lines, arrows, arcs, spline curves, and text. These may be placed anywhere, at positions specified absolutely or in terms of previous objects. The example below illustrates the style and basic capabilities of the language.



This picture was created with the input

```
.PS
ellipse "document"
arrow
box "PIC"
arrow
box "TBL/EQN" "(optional)" dashed
arrow
box "TROFF"
arrow
ellipse "typesetter"
.PE
```

Pic is a *troff* preprocessor; it passes most of its input through untouched, but translates commands between `.PS` and `.PE` into *troff* commands that draw the pictures.

Revised, May, 1991

† This is a revised version of [5].

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1. Introduction

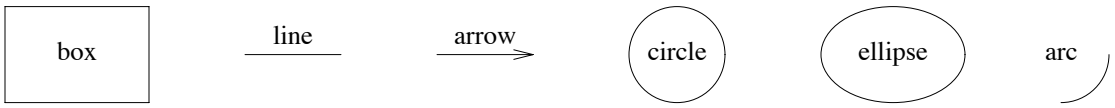
Pic is a language for drawing pictures. It operates as yet another *troff* [8] preprocessor (in the same style as *eqn* [7] and *tbl* [4]), with pictures delimited by `.PS` and `.PE`.

Pic was inspired partly by Chris Van Wyk's early work on *ideal* [9]; it has somewhat the same capabilities, but quite a different flavor. In particular, *pic* is much more procedural—a picture is drawn by specifying (sometimes in painful detail) the motions that one goes through to draw it. Other direct influences include the PICTURE language [2], the V viewgraph language [1], and, more recently, new features from the *grap* language [3] for typesetting graphs.

This paper is primarily a user's manual for *pic*; a discussion of design issues and user experience may be found in [6]. The next section shows how to use *pic* in the most simple way. Subsequent sections describe how to change the sizes of objects when the defaults are wrong, and how to change their positions when the standard positioning rules are wrong. An appendix describes the language succinctly and summarizes changes since the last manual.

2. Basics

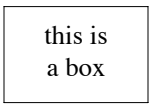
Pic provides boxes, lines, arrows, circles, ellipses, arcs, and splines (smooth curves), plus facilities for positioning and labeling them. The picture below shows all of the fundamental objects (except for splines) in their default sizes:



Each picture begins with `.PS` and ends with `.PE`; between them are commands to describe the picture. Each command is typed on a line by itself. For example

```
.PS
box "this is" "a box"
.PE
```

creates a standard box (¾ inch wide, ½ inch high) and centers the two pieces of text in it:



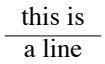
Each line of text is a separate quoted string. Quotes are mandatory, even if the text contains no blanks. (Of course there needn't be any text at all.) Each line will be printed in the current size and font, centered horizontally, and separated vertically by the current *troff* line spacing. *Pic* does not center the complete drawing itself, but the default definitions of `.PS` and `.PE` in the `-ms` macro package do.

† This is a revised version of [5].

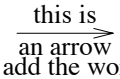
You can use `circle` or `ellipse` in place of `box`:

Text is centered on lines and arrows; if there is more than one line of text, the lines are centered above and below:

```
line "this is" "a line"
```

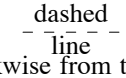



```
arrow "this is" "an arrow"
```



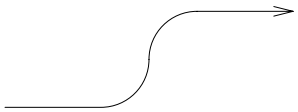
Boxes and lines may be dashed or dotted; just add the word `dashed` or `dotted` after `box` or `line`:

```
line dashed "dashed" "line"
```



Arcs by default turn 90 degrees counterclockwise from the current direction; you can make them turn clockwise by saying `arc cw`:

```
line; arc; arc cw; arrow
```



A spline might well do this job better; we will return to that shortly.

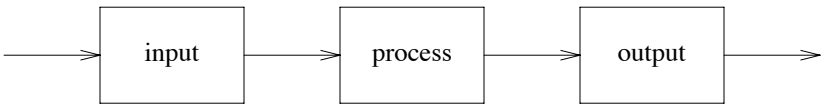
As you might guess,

```
arc; arc; arc; arc
```

draws a circle, though not very efficiently. Notice that several commands can be put on a single line if they are separated by semicolons.

Objects are normally drawn one after another, left to right, and connected at the obvious places:

```
arrow; box "input"; arrow; box "process"; arrow; box "output"; arrow
```

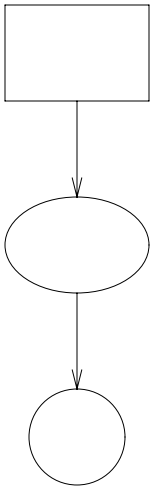


One way to leave a space is with `move`:

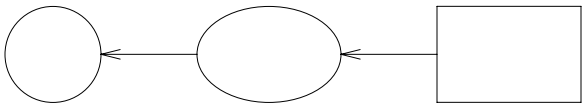
```
box; move; box; move; box
```

Although objects are normally connected left to right, this can be changed. If you specify a direction (as a separate object), subsequent objects will be joined in that direction:

```
down; box; arrow; ellipse; arrow; circle
```



```
left; box; arrow; ellipse; arrow; circle
```



Each new picture begins going to the right.

Normally, figures are drawn at a fixed scale, with objects of a standard size. It is possible, however, to arrange that a figure be expanded or shrunk to fit a particular width. If the `.PS` line contains a number, the drawing is forced to be that many inches wide, with the height scaled proportionately. Thus

```
.PS 3.5
```

causes the picture to be 3.5 inches wide. If two dimensions are specified, the second is the height.

Pic is pretty dumb about the size of text in relation to the size of boxes, circles, and so on. There is no way to say ''make a box that just fits around this text'' or ''make this text fit inside this circle'' or ''draw a line as long as this text.'' Tight fitting of text can generally only be done by trial and error.

Speaking of errors, if you make a grammatical error in the way you describe a picture, *pic* will complain and try to indicate where. For example, the invalid input

```
box arrow box
```

will draw the message

```
pic: syntax error near line 5, file -
 context is
        box >>>  arrow <<<  box
```

The brackets point to the place where the error was first noted; it sometimes follows the word in error, although in this example it's right on target. The filename '`-`' is the standard input.

3. Controlling Sizes

This section deals with how to control the sizes of objects when the default sizes are not what is wanted. The next section deals with positioning them when the default positions are not right.

Each object that *pic* knows about (boxes, circles, etc.) has associated dimensions, like height, width, radius, and so on. By default, *pic* tries to choose sensible default values for these dimensions, so that simple pictures can be drawn with a minimum of fuss and bother. All of the figures and motions shown so far have been in their default sizes:

box	¾" wide × ½" high
circle	½" diameter
ellipse	¾" wide × ½" high
arc	½" radius
line or arrow	½" long
move	½" in the current direction

When necessary, you can make any object any size you want:

```
box width 3 height 0.1; circle radius 0.1
```

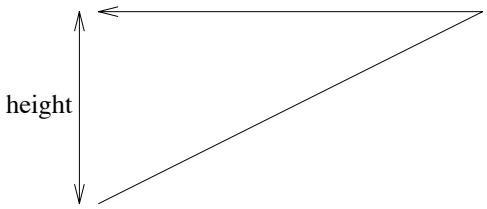
All positions and dimensions are in inches, so the box is 3 inches wide and 1/10 inch high and the circle has radius 1/10 inch.

An attribute like `width` changes only the one instance of the object. You can also change the default size for all objects of a particular type by assigning values to *pic* variables; this will be discussed in Section 6.

The attributes of `height` (which you can abbreviate to `ht`) and `width` (or `wid`) apply to boxes, circles, ellipses, and to the head on an arrow. The attributes of `radius` (or `rad`) and `diameter` (or `diam`) can be used for circles and arcs if they seem more natural.

Lines and arrows are most easily drawn by specifying the amount of motion from where you are right now, in terms of directions. Accordingly the words `up`, `down`, `left` and `right` and an optional distance can be attached to `line`, `arrow`, and `move`:

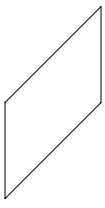
```
line up 1 right 2
arrow left 2
move left 0.1
line <-> down 1 "height " rjust
```



The notation `<->` indicates a two-headed arrow; use `->` for a head on the end and `<-` for one on the start. Lines and arrows are really the same thing; in fact, `arrow` is a synonym for `line ->`.

If you don't specify any distance after `up`, `down`, etc., *pic* uses the standard distance:

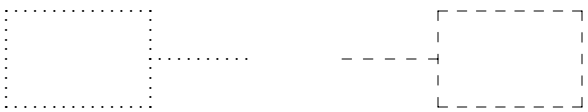
```
line up right; line down; line down left; line up
```



If you omit the direction associated with a distance, the current direction is used.

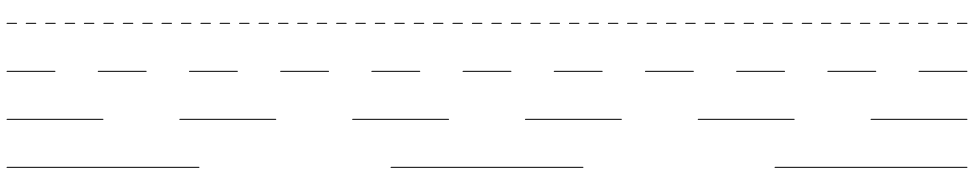
Boxes and lines may be dotted or dashed:

```
box dotted; line dotted; move; line dashed; box dashed
```



If there is a number after `dot`, the dots will be approximately that far apart. You can also control the size of the dashes (at least somewhat): if there is a length after the word `dashed`, the dashes will be that long, and the intervening spaces will be as close as possible to that size:

```
line right 5 dashed; move left 5 down .25; right
line right 5 dashed 0.25; move left 5 down .25; right
line right 5 dashed 0.5; move left 5 down .25; right
line right 5 dashed 1
```



Dotted or dashed attributes apply only to lines and boxes.

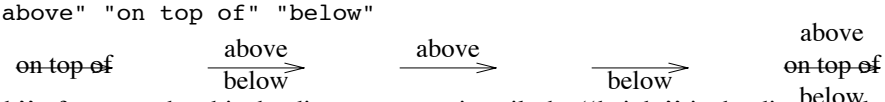
You can make any object invisible by adding the word `invis` after it. This is particularly useful for positioning things correctly near text:

```
box invis "input"; arrow; box invis "output"
```

input ⟶ output

Text may be positioned on lines and arrows:

```
arrow "on top of"; move
arrow "above" "below"; move
arrow "above" above; move
arrow "below" below; move
arrow "above" "on top of" "below"
```



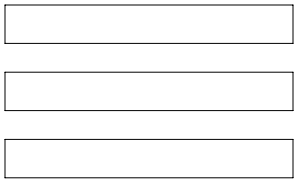
The ‘‘width’’ of an arrowhead is the distance across its tail; the ‘‘height’’ is the distance along the shaft. The arrowheads in this picture are default size and shape.

As we said earlier, arcs go 90 degrees counterclockwise from where you are right now, and `arc cw` changes this to clockwise. The default radius is the same as for circles, but you can change it with the `rad` attribute. It is also easy to draw arcs between specific places; this will be described in the next section.

To put an arrowhead on an arc, use one of `<-`, `->` or `<->`, as with lines.

In all cases, unless an explicit dimension for some object is specified, you will get the default size. If you want an object to have the same size as the previous one of that kind, add the word `same`. Thus in the set of boxes given by

```
down; box ht 0.2 wid 1.5; move down 0.15; box same; move same; box same
```



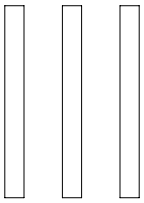
the dimensions set by the first `box` are used several times; similarly, the amount of motion for the second `move` is the same as for the first one.

You can change the default sizes of objects by assigning values to the variables that define their values. Here is the list, with their default values:

```
boxwid = 0.75;          boxht = 0.5
linewid = 0.75;         lineht = 0.5
circlerad = 0.25;       arcrad = 0.25
ellipsewid = 0.75;      ellipseht = 0.5
movewid = 0.75;         moveht = 0.5
textwid = 0;            textht = 0
arrowwid = 0.05;        arrowht = 0.1     (These refer to the arrowhead.)
dashwid = 0.05;         arrowhead = 2     (Arrowhead fill style)
maxpsht = 8.5;          maxpswid = 11     (Maximum picture dimensions)
fillval = 0.3;          scale = 1
```

So if you want all your boxes to be long and skinny, and relatively close together,

```
boxwid = 0.1; boxht = 1
movewid = 0.2
box; move; box; move; box
```



Setting the variable `arrowhead` to a value like 7 causes arrowheads to be filled by overstriking; the default is 2:

```
arrowhead = 7; arrow; move; arrowhead = 2; arrow
```


Pic works internally in inches. Setting the variable `scale` to some value causes all dimensions to be scaled down by that value. Thus, for example, `scale=2.54` causes dimensions to be interpreted as centimeters.

The numbers given in the `.PS` line override the dimensions given in the picture; these can be used to force a picture to a particular width and height. Experience indicates that a good way to get a picture of the right size is to enter its dimensions in inches, then if necessary add a width and perhaps height to the `.PS` line.

Once set, variables like `boxht` retain their values from one picture to the next. You can reset variables to their default values by listing them in a `reset` statement:

```
reset boxht, boxwid
```

A bare `reset` resets all variables.

There is a minimal facility for filling or shading objects, intended for Postscript output devices. The attribute `fill` *expr* sets the gray scale value to *expr*; the default, determined by the variable `fillval`, is 0.3. Following Postscript, smaller values are darker. Thus:

```
box fill
box ht boxht/2 wid boxwid/2 "hello" at last box
```

`fill` currently only applies to boxes, circles, and ellipses.

4. Controlling Positions

You can place things anywhere you want; *pic* provides a variety of ways to talk about positions. *Pic* uses a standard Cartesian coordinate system with *x* increasing rightwards and *y* increasing upwards, so any point or object has an *x* and *y* position, measured in inches. The first object is placed with its start at position 0,0 by default. The *x,y* position of a box, circle or ellipse is its geometric center; the position of a line or spline or motion is its beginning; the position of an arc is the center of the corresponding circle.

Position modifiers like `from`, `to`, `by` and `at` are followed by an *x,y* pair, and can be attached to boxes, circles, lines, motions, and so on, to specify or modify a position.

You can also use `up`, `down`, `right`, and `left` with `line` and `move`:

```
box ht 0.2 wid 0.2 at 0,0 "1"
move right 0.5                  # or "move to 0.5,0"
box ht 0.2 wid 0.2 "2"
move right 0.5                  # or "move 0.5" or "move same"
box ht 0.2 wid 0.2 "3"
```

Comments can be used in pictures; they begin with a # and end at the end of the line.

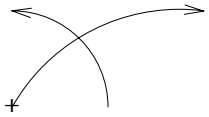
Attributes like `ht` and `wid` and positions like `at` can be written out in any order. So

```
box ht 0.2 wid 0.2 at 0,0
box at 0,0 wid 0.2 ht 0.2
box ht 0.2 at 0,0 wid 0.2
```

are all equivalent, though the last is harder to read and thus less desirable.

The `from` and `to` attributes are particularly useful with arcs, to specify the endpoints. By default, arcs are drawn counterclockwise,

```
"+" at 0,0
arc -> from 0.5,0 to 0,0.5
arc -> cw from 0,0 to 1,0.5
```



The radius can be made large to provide flat arcs:

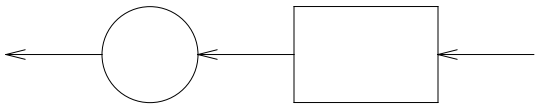
```
arc -> cw from 0,0 to 2,0 rad 15
```


If the circle is under-specified, *pic* guesses a radius and/or center; you will have to provide them explicitly if the guess is wrong.

We said earlier that objects are normally connected left to right. This is an over-simplification. The truth is that objects are connected together in the direction specified by the most recent `up`, `down`, `left` or `right` (either alone or as part of some object). Thus, in

```
arrow left; box; arrow; circle; arrow
```

the `left` implies connection towards the left:

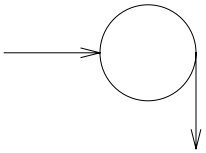


This could also be written as

```
left; arrow; box; arrow; circle; arrow
```

Objects are joined in the direction determined by the last `up`, `down`, etc., with the entry point of the second object attached to the exit point of the first (which is fixed at the time of entry). Entry and exit points for boxes, circles and ellipses are on opposite sides. This automatic connection and direction selection works well if the direction doesn't change but it will occasionally surprise you:

```
arrow; circle; down; arrow
```



The arrow comes out of the right side of the circle, not the bottom, as might be expected.

If a set of commands is enclosed in braces `{...}`, the current position and direction of motion when the group is finished will be exactly where it was when entered. Nothing else is restored. There is also a more general way to group objects, using `[` and `]`, which is discussed in Section 9.

5. Labels and Corners

Objects can be labelled or named so that you can talk about them later. For example,

```
Box1:   box
        # ... other stuff ...
        move to Box1
```

Place names *must* begin with an upper case letter (to distinguish them from variable names, which begin with lower case letters). The name refers to the ''center'' of the object, which is the geometric center for most things.

Other combinations also work:

```
line from Box1 to Box2
move to Box1 up 0.1 right 0.2
move to Box1 + 0.2,0.1  # same as previous
line to Box1 - 0.5,0
```

The reserved name `Here` may be used to refer to the current position.

Labels can be reset several times in a single picture, so a statement like

```
Box1:  Box1 + 1,1
```

is perfectly legal.

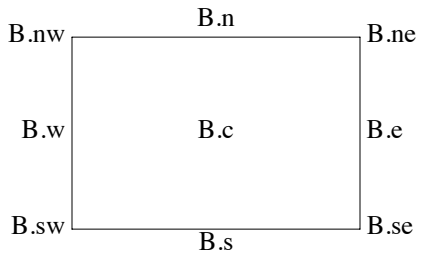
You can also refer to previously drawn objects of each type, using the word `last`. For example, given the input

```
box "A"; circle "B"; box "C"
```

then '`last box`' refers to box `C`, '`last circle`' refers to circle `B`, and '`2nd last box`' refers to box `A`. Numbering of objects can also be done from the beginning, so boxes `A` and `C` are '`1st box`' and '`2nd box`' respectively.

To cut down the need for explicit coordinates, objects have ''corners'' named by compass points:

```
B: box "B.c" ht 1 wid 1.5
        " B.e" at B.e ljust
        " B.ne" at B.ne ljust
        " B.se" at B.se ljust
        "B.s" at B.s below
        "B.n" at B.n above
        "B.sw " at B.sw rjust
        "B.w " at B.w rjust
        "B.nw " at B.nw rjust
```

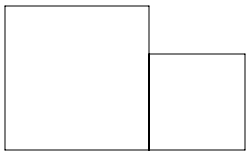


Note the use of `ljust`, `rjust`, `above`, and `below` to alter the default positioning of text, and of a blank within some strings to help space them away from a vertical line.

Lines and arrows have a `start`, an `end` and a `center` in addition to corners. Circles and ellipses have corners too; an arc has the same corners as the circle of which it is a part. The words `left`, `right`, `top`, and `bottom` are synonyms for `west`, `east`, `north` and `south`.

It is often easiest to position objects by positioning some part of one at some part of another, for example the southwest corner of one at the southeast corner of another. The `with` attribute permits this kind of positioning:

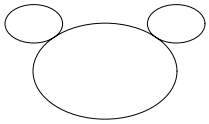
```
box ht 0.75 wid 0.75
box ht 0.5 wid 0.5 with .sw at last box.se
```



Notice that the corner after `with` is written `.sw`.

As another example, consider

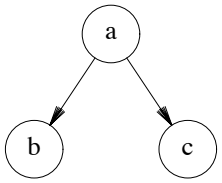
```
ellipse
ellipse ht .2 wid .3 with .se at 1st ellipse.nw
ellipse ht .2 wid .3 with .sw at 1st ellipse.ne
```



Sometimes it is desirable to have a line intersect a circle at a point which is not one of the eight compass points that *pic* knows about. In such cases, the proper visual effect can be obtained by using the attribute `chop` to

chop off part of the line:

```
circlerad = 0.15; arrowhead = 7
circle "a"
circle "b" at 1st circle - (0.4, 0.6)
circle "c" at 1st circle + (0.4, -0.6)
arrow from 1st circle to 2nd circle chop
arrow from 1st circle to 3rd circle chop
```



By default the line is chopped by `circlerad` at each end. This may be changed:

`line ...` `chop` *r*

chops both ends by *r*, and

`line ...` `chop` *r1* `chop` *r2*

chops the beginning by *r1* and the end by *r2*. More complicated intersections can be computed with the built-in trigonometric functions listed in the next section.

There is one other form of positioning that is sometimes useful, to refer to a point some fraction of the way between two other points. This can be expressed in *pic* as

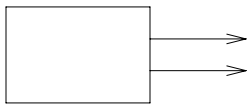
fraction `of the way between` *position1* `and` *position2*

where *fraction* is any expression, and *position1* and *position2* are any positions. You can abbreviate this rather windy phrase; ''of the way'' is optional, and the whole thing can be written instead as

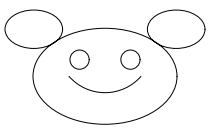
fraction `<` *position1* `,` *position2* `>`

As a pair of examples:

```
box
arrow right from 1/3 of the way between last box.ne and last box.se
arrow right from 2/3 <last box.ne, last box.se>
```



```
A:  ellipse
    ellipse ht .2 wid .3 with .se at 1st ellipse.nw
    ellipse ht .2 wid .3 with .sw at 1st ellipse.ne
    circle rad .05 at 0.5 <A.nw,A.c>
    circle rad .05 at 0.5 <A.ne,A.c>
    arc from 0.25 <A.w,A.e> to 0.75 <A.w,A.e>
```



Naturally, the distance given by *fraction* can be greater than 1 or less than 0.

Advice: experience suggests that the easiest way to position objects is by placing them relative to previous

objects and places, using `with`, `at`, etc. This is better than using `move`; you should generally avoid `move`.

6. Variables, Expressions and Built-in Functions

It's generally a bad idea to write everything in absolute coordinates if you are likely to change things. *Pic* variables let you parameterize your picture:

```
a = 0.5;  b = 1

box wid a ht b
ellipse wid a/2 ht 1.5*b
Box2:  Box1 - (a/2, b/2)
```

Expressions may use the standard operators `+`, `-`, `*`, `/`, `%`, `^` (exponentiation), and parentheses for grouping.

The most important variables are the predefined ones for controlling the default sizes of objects, listed in Section 3. These may be set at any time in any picture, and retain their values from picture to picture until reset.

You can use the height, width, radius, and *x* and *y* coordinates of any object or corner in an expression:

```
Box1.x          # the x coordinate of the center of Box1
Box1.ne.y       # the y coordinate of the northeast corner of Box1
Box1.wid        # the width of Box1
Box1.ht         # and its height
2nd last circle.rad     # the radius of the 2nd last circle
```

Any pair of expressions enclosed in parentheses defines a position; furthermore such positions can be added or subtracted to yield new positions:

```
(x, y)
(x1, y1) + (x2, y2)
```

If p_1 and p_2 are positions, then (p_1, p_2) refers to the point (p_1`.x`, p_2`.y`).

Pic provides a small collection of standard functions:

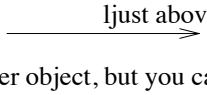
`sin`(*expr*), `cos`(*expr*), `atan2`(*y*,*x*)	(angle in radians)
`log`(*expr*), `exp`(*expr*)	(Beware: both base 10)
`sqrt`(*expr*), `max`(e_1,e_2), `min`(e_1,e_2)	
`int`(*expr*)	(integer part of *expr*)
`rand`()	(random number between 0 and 1)

7. More on Text

Normally, text is centered at the geometric center of the object it is associated with. The attribute `ljust` causes the left end to be at the specified point (which means that the text lies to the right of the specified place!), and `rjust` puts the right end at the place. `above` and `below` center the text one half line space in the given direction.

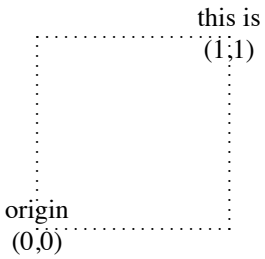
Text attributes can be compounded:

```
arrow 1 "ljust above" ljust above
```



Text is most often an attribute of some other object, but you can also have self-standing text:

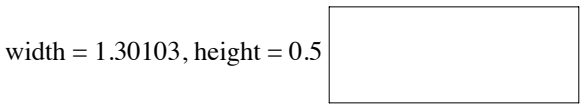
```
"origin" "(0,0)" at 0,0
"this is" "(1,1)" at 1,1
box ht 1 wid 1 dotted with .sw at 0,0
```



In effect, *n* text strings are contained in an invisible box of width `textwid` and height *n* × `textht`. The variables `textwid` and `textht` may be set to any values; they are normally zero.

A list of numeric expressions can be converted to a formatted string with the `sprintf` function and used anywhere a quoted string can be:

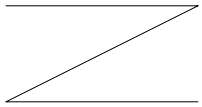
```
B: box wid log(20)
   sprintf("width = %g, height = %g ", B.wid, B.ht) rjust at B.w
```



8. Lines and Splines

A ‘‘line’’ may actually be a path, that is, it may consist of connected segments:

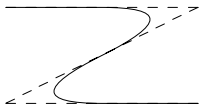
```
line right 1 then down .5 left 1 then right 1
```



The word `then` separates components of the path.

A spline is a smooth curve guided by a set of straight lines just like the line above. It begins at the same place, ends at the same place, and in between is tangent to the mid-point of each guiding line. The syntax for a spline is identical to a (path) line except for using `spline` instead of `line`:

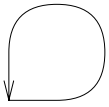
```
line dashed right 1 then down .5 left 1 then right 1
spline from start of last line \
  right 1 then down .5 left 1 then right 1
```



(Long input lines can be split by ending each piece with a backslash.)

The elements of a path, whether line or spline, are specified as a series of points, either in absolute terms or by `up`, `down`, etc.

```
spline right then up then left then down ->
```



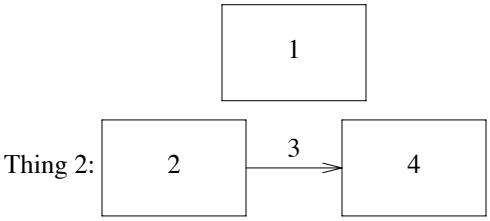
```
spline right then up left then down ->
```

Notice that arrowheads may be put on the ends of a line or spline.

9. Blocks

Any sequence of *pic* statements may be enclosed in brackets `[` and `]` to form a block, which can then be treated as a single object, and manipulated rather like an ordinary box:

```
box "1"
[ box "2"; arrow "3" above; box "4" ] with .n at last box.s - (0,0.1)
"Thing 2: " rjust at last [].w
```



Notice that ‘‘last’’-type constructs treat blocks as a unit and don’t look inside for objects: ‘‘`last box.s`’’ refers to box 1, not box 2 or 4. You can use `last []`, etc., just like `last box`.

Blocks have the same compass corners as boxes (determined by the bounding box). It is also possible to position a block by placing either an absolute coordinate (like `0,0`) or an internal label (like `A`) at some external point, as in

```
[ ...; A: ...; ... ] with .A at ...
```

By default, blocks join with other things as boxes do, at the center of the appropriate side.

Names of variables and places within a block are local to that block, and thus do not affect variables and places of the same name outside. (In particular, that includes the built-in variables like `boxwid`, etc.; if they are set within a block, they revert to their original values when the block is left.) You can get at the internal place names with constructs like

```
last [].A
```

or

```
B.A
```

where `B` is a name attached to a block:

```
B:  [ ... ;  A: ...;  ]
```

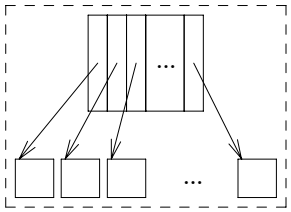
When combined with `define` statements (next section), blocks provide a reasonable simulation of a procedure mechanism.

Although blocks nest, it is currently possible to look only one level deep with constructs like `B.A`, although `A` may be further qualified by a corner name (i.e., `B.A.sw` or `top of B.A` are legal).

The following example illustrates most of the points made above about how blocks work:

```
h = .5;  dh = .02;  dw = .1
[
        Ptr: [
                boxht = h; boxwid = dw
                A: box
                B: box
                C: box
                box wid 2*boxwid "..."
                D: box
        ]
        Block: [
                boxht = 2*dw; boxwid = 2*dw
                movewid = 2*dh
                A: box; move
                B: box; move
                C: box; move
                box invis "..." wid 2*boxwid; move
                D: box
        ] with .t at Ptr.s - (0,h/2)
        arrow from Ptr.A to Block.A.nw + (dh,0)
        arrow from Ptr.B to Block.B.nw + (dh,0)
        arrow from Ptr.C to Block.C.nw + (dh,0)
        arrow from Ptr.D to Block.D.nw + (dh,0)
]
box dashed ht last [].ht+dw wid last [].wid+dw at last []
```

This produces



10. Macros

Pic provides a basic macro facility. In the simplest form,

`define` *name* `{` *replacement text* `}`

defines *name* to be the *replacement text*. Any subsequent occurrence of *name* will be replaced by *replacement text*.

Macros may have arguments. If the replacement text of a macro definition contains occurrences of `$1`, `$2`, etc., these will be replaced by the corresponding actual arguments when the macro is invoked. The invocation for a macro with arguments is

```
name(arg1, arg2, ...)
```

Non-existent arguments are replaced by null strings. Macro definitions last from picture to picture; a macro definition can be removed by

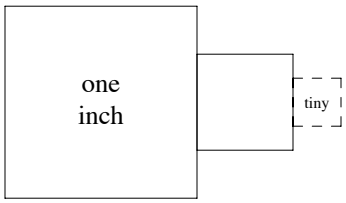
`undef` *macro-name*

As an example, one might define a `square` by

```
define square { box ht $1 wid $1  $2 }
```

and use it as

```
square(1, "one" "inch")
square(0.5)
square(0.25, "\s-4tiny\s+4" dashed)
```



Notice how the second argument may be used to pass in arbitrary contents.

Coordinates like *x,y* may be enclosed in parentheses, as in (*x,y*), so they can be included in a macro argument.

11. File Copy

The statement

`copy "`*filename*`"`

inserts the contents of the named file at that point in the input. Any `.PS` or `.PE` lines within the file are ignored, so previously prepared pictures can be used as parts of larger ones without editing.

Pic also provides the `copy thru` mechanism found in *grap*:

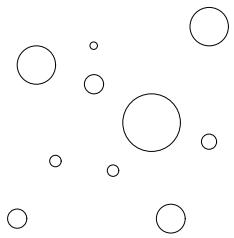
`copy "`*file*`" thru` *macro-name*

copies *file*, treating each line as an invocation of the named macro (each field being an argument). A literal macro may be used instead of a name:

`copy "`*file*`" thru {` *macro replacement text* `}`

and if no file name is given, the remainder of the input until the next `.PE` is used. So to plot a set of circles at points whose coordinates and radii are included in-line:

```
copy thru { circle rad $3 at $1,$2 }
0 0 .05
1 1 .1
...
```



The `sh` command executes an arbitrary commandline:

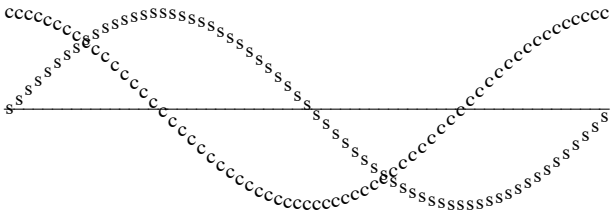
`sh {` *anything* `}`

Macros within *anything* are expanded first.

12. Loops and Conditionals

Pic provides an `if` statement and a `for` loop.

```
pi = atan2(0,-1)
for i = 0 to 2 * pi by 0.1 do {
        "—" at i/2, 0
        "s" at i/2, sin(i)/2
        "c" at i/2, cos(i)/2
}
```



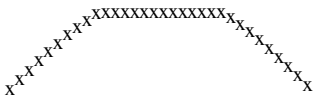
The `by` clause is optional; if the value is preceded by a `*`, the steps are multiplicative, not additive. The body of the loop is delimited by braces, which are also used for definitions, `copy`, `sh` and `if` statements.

The `if` statement is

`if` *expression* `then {` *anything* `} else {` *anything* `}`

where the `else` clause is optional. The *expression* may use the usual relational operators: `==`, `!=`, `>`, `>=`, `<`, `<=`, `&&`, and `||`.

```
pi = atan2(0,-1)
for i = 0 to pi by 0.1 do {
        if (s = sin(i)) > 0.8 then { s = 0.8 }
        "x" at i/2, s/2
}
```



A string comparison using `==` or `!=` is also permitted, to compare quoted strings:

`if "`*string1*`" == "`*string2*`" then ...`

13. *Troff* Interface

Pic is usually run as a *troff* preprocessor:

```
pic file | troff -ms
```

Run it before *eqn* if it is also present.

If the `.PS` line looks like

```
.PS <file
```

then the contents of `file` are inserted in place of the `.PS` line, whether or not the file contains `.PS` or `.PE`. (This feature is deprecated in favor of the `copy` statement.)

Pic copies the `.PS` and `.PE` lines from input to output intact, except that it adds two things on the same line as the `.PS`:

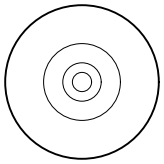
```
.PS h w
```

`h` and `w` are the picture height and width in units. The `-ms` macro package has definitions for `.PS` and `.PE` that cause pictures to be centered and offset a bit from surrounding text. (See the appendix.)

If ‘‘`.PF`’’ is used instead of `.PE`, the position after printing is restored to where it was before the picture started, instead of being at the bottom. (‘‘`F`’’ is for ‘‘flyback.’’)

Any input line that begins with a period is assumed to be a *troff* command that makes sense at that point; it is copied to the output at that point in the document. It is asking for trouble to add vertical space or in any way fiddle with the line spacing here, but point size and font changes are generally harmless:

```
.ps 24
circle radius .4 at 0,0
.ps 12
circle radius .2 at 0,0
.ps 8
circle radius .1 at 0,0
.ps 6
circle radius .05 at 0,0
.ps 10  \" don't forget to restore size
```



Pic does preserve the state of *troff*'s fill mode across pictures.

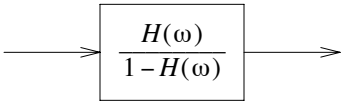
It is also safe to include sizes, fonts and local motions within quoted strings)..."" in *pic*, so long as whatever changes are made are unmade before exiting the string. For example, to print text in Helvetica Bold 2 points larger:

```
ellipse "\s+2\f(HBSmile!\fP\s-2"
```

This is essentially the same rule as applies in *eqn*.

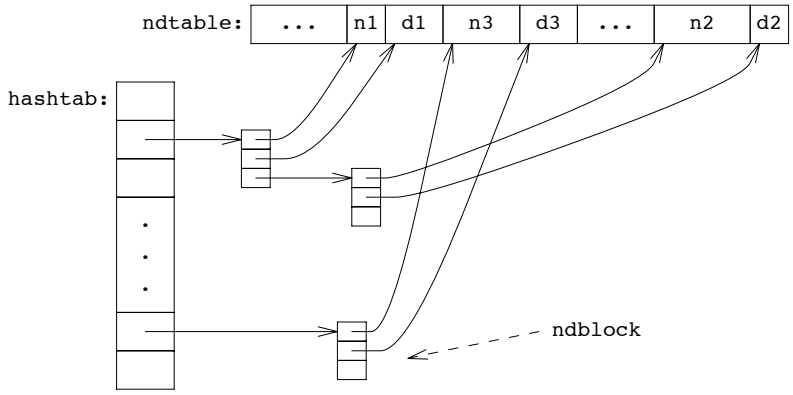
There is a subtle problem with complicated equations inside *pic* pictures — they come out wrong if *eqn* has to leave extra vertical space for the equation. If your equation involves more than subscripts and superscripts, you must add to the beginning of each equation the extra information `space 0`:

```
arrow
box "$space 0 {H( omega )} over {1 - H( omega )}$"
arrow
```

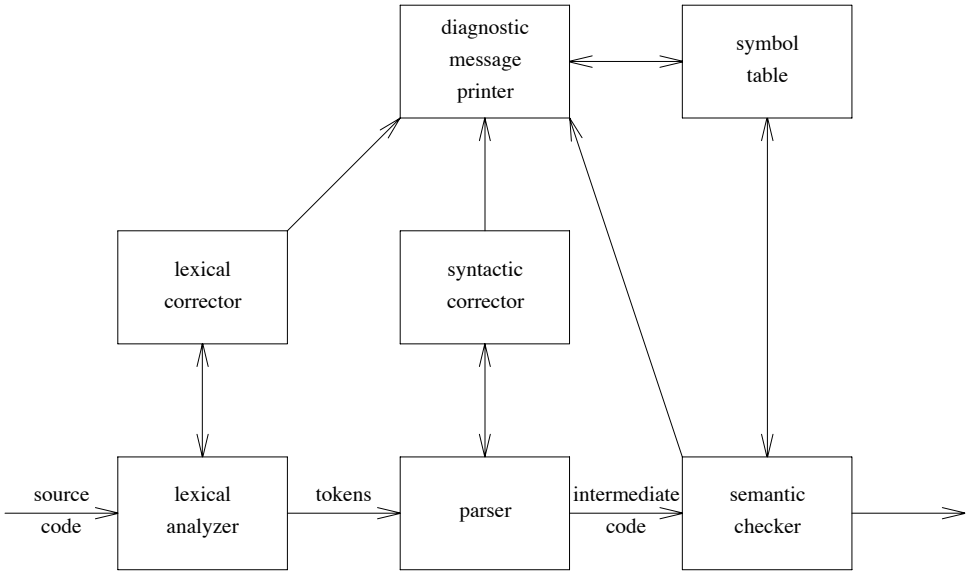


14. Some Examples

Here are a handful of larger examples:



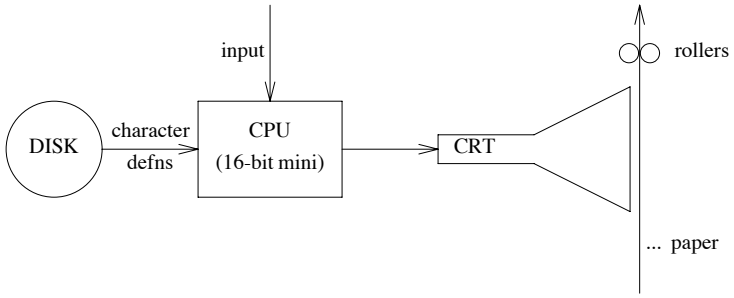

```
define ndblock {
        box wid boxwid/2 ht boxht/2
        down;  box same with .t at bottom of last box;   box same
}
boxht = .2; boxwid = .3; circlerad = .3; dx = 0.05
down; box; box; box; box ht 3*boxht "." "." "."
L: box; box; box invis wid 2*boxwid "hashtab:" with .e at 1st box .w
right
Start: box wid .5 with .sw at 1st box.ne + (.4,.2) "..."
N1: box wid .2 "n1";  D1: box wid .3 "d1"
N3: box wid .4 "n3";  D3: box wid .3 "d3"
box wid .4 "..."
N2: box wid .5 "n2";  D2: box wid .2 "d2"
arrow right from 2nd box
ndblock
spline -> right .2 from 3rd last box then to N1.sw + (dx,0)
spline -> right .3 from 2nd last box then to D1.sw + (dx,0)
arrow right from last box
ndblock
spline -> right .2 from 3rd last box to N2.sw-(dx,.2) to N2.sw+(dx,0)
spline -> right .3 from 2nd last box to D2.sw-(dx,.2) to D2.sw+(dx,0)
arrow right 2*linewid from L
ndblock
spline -> right .2 from 3rd last box to N3.sw + (dx,0)
spline -> right .3 from 2nd last box to D3.sw + (dx,0)
circlerad = .3
circle invis "ndblock"  at last box.e + (1.2,.2)
arrow dashed from last circle.w to last box chop 0 chop .3
box invis wid 2*boxwid "ndtable:" with .e at Start.w
```




```
.PS 5
.ps 8
        arrow "source" "code"
LA:     box "lexical" "analyzer"
        arrow "tokens" above
P:      box "parser"
        arrow "intermediate" "code"
Sem:    box "semantic" "checker"
        arrow

        arrow <-> up from top of LA
LC:     box "lexical" "corrector"
        arrow <-> up from top of P
Syn:    box "syntactic" "corrector"
        arrow up
DMP:    box "diagnostic" "message" "printer"
        arrow <-> right  from right of DMP
ST:     box "symbol" "table"
        arrow from LC.ne to DMP.sw
        arrow from Sem.nw to DMP.se
        arrow <-> from Sem.top to ST.bot
.PE
```

There are eighteen objects (boxes and arrows) in the picture, and one line of *pic* input for each; this seems like an acceptable level of verbosity.



Basic Digital Typesetter

```
.PS
.ps -2
        circle "DISK"
        arrow "character" "defns"
CPU:    box "CPU" "(16-bit mini)"
        { arrow <- from top of CPU up "input " rjust }
        arrow
CRT:    "   CRT" ljust
        line from CRT - 0,0.075 up 0.15 \
                then right 0.5 \
                then right 0.5 up 0.25 \
                then down 0.5+0.15 \
                then left 0.5 up 0.25 \
                then left 0.5
Paper:  CRT + 1.05,0.75
        arrow <- from Paper down 1.5
        " ...  paper" ljust at end of last arrow + 0, 0.25
        circle rad 0.05 at Paper + (-0.055, -0.25)
        circle rad 0.05 at Paper + (0.055, -0.25)
        "   rollers" ljust at Paper + (0.1, -0.25)
.ps +2
.PE
.ce
Basic Digital Typesetter
```

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More recent versions of *pic* have benefited greatly from adventurous use by Jon Bentley and Ravi Sethi; their comments on the manual are also much appreciated.

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Appendix A: *Pic* Reference Manual

Pictures

The top-level object in *pic* is the ''picture'':

picture:
`.PS` *optional-width optional-height*
element-list
`.PE`

If *optional-width* is present, the picture is made that many inches wide, regardless of any dimensions used internally. The height is scaled in the same proportion unless *optional-height* is present. If instead the line is

```
.PS <f
```

the file `f` is inserted in place of the `.PS` line. If `.PF` is used instead of `.PE`, the position after printing is restored to what it was upon entry.

In no case will the picture be larger than `maxpsht` × `maxpswid`.

Elements

An *element-list* is a list of elements (what else?); the elements are

element:
primitive attribute-list
placename `:` *element*
placename `:` *position*
var `=` *expr*
direction
`{` *element-list* `}`
`[` *element-list* `]`
`for` *var* `=` *expr* `to` *expr* `by` *expr* `do {` *anything* `}`
`if` *expr* `then {` *anything* `} else {` *anything* `}`
`copy` *file*
`copy thru` *macro*
`copy` *file* `thru` *macro*
`sh {` *commandline* `}`
`print` *expr*
`reset` *optional var-list*
troff-command

Elements are separated by newlines or semicolons; a long element may be continued by ending the line with a backslash. Comments are introduced by a # and terminated by a newline.

Variable names begin with a lower case letter; place names begin with upper case. Place and variable names retain their values from one picture to the next.

The current position and direction of motion are saved upon entry to a `{...}` block and restored upon exit.

Elements within a block enclosed in `[...]` are treated as a unit; the dimensions are determined by the extreme points of the contained objects. Names, variables, and direction of motion within a block are local to that block.

troff-command is any line that begins with a period. Such a line is assumed to make sense in the context where it appears; accordingly, if it doesn't work, don't call.

Primitives

The primitive objects are

primitive`:`
`box`
`circle`
`ellipse`
`arc`
`line`
`arrow`
`spline`
`move`
text-list

`arrow` is a synonym for `line ->`.

Attributes

An *attribute-list* is a sequence of zero or more attributes; each attribute consists of a keyword, perhaps followed by a value.

attribute`:`

`h(eigh)t` *expr*	`wid(th)` *expr*
`rad(ius)` *expr*	`diam(eter)` *expr*
`up` *opt-expr*	`down` *opt-expr*
`right` *opt-expr*	`left` *opt-expr*
`from` *position*	`to` *position*
`at` *position*	`with` *corner*
`by` *expr, expr*	`then`
`dotted` *opt-expr*	`dashed` *opt-expr*
`chop` *opt-expr*	`->  <-  <->`
`invis`	`solid`
`fill` *opt-expr*	`same`
text-list	*expr*

Missing attributes and values are filled in from defaults. Not all attributes make sense for all primitives; irrelevant ones are silently ignored. The attribute `at` causes the geometrical center to be put at the specified place; `with` causes the position on the object to be put at the specified place. For lines, splines and arcs, `height` and `width` refer to arrowhead size. A bare *expr* implies motion in the current direction.

Text

Text is normally an attribute of some primitive; by default it is placed at the geometrical center of the object. Stand-alone text is also permitted. A *text-list* is a list of text items; a text item is a quoted string optionally followed by positioning requests:

text-item`:`
`"..."` *positioning ...*
`sprintf("`*format*`",` *expr*`, ...)` *positioning ...*
positioning`:`
`center  ljust  rjust  above  below`

If there are multiple text items for some primitive, they are centered vertically except as qualified. Positioning

requests apply to each item independently.

Text items can contain *troff* commands for size and font changes, local motions, etc., but make sure that these are balanced so that the entering state is restored before exiting.

Positions and places

A position is ultimately an *x,y* coordinate pair, but it may be specified in other ways.

position:
expr, expr
place ± *expr, expr*
place ± (*expr, expr*)
(*position*, *position*)
expr [of the way] between *position* and *position*
expr < *position* , *position* >
(*position*)

place:
placename optional-corner
corner of *placename*
nth primitive optional-corner
corner of *nth primitive*
Here

An *optional-corner* is one of the eight compass points or the center or the start or end of a primitive.

optional-corner:
.n .e .w .s .ne .se .nw .sw .c .start .end
corner:
top bot left right start end

Each object in a picture has an ordinal number; *nth* refers to this.

nth:
*n*th
*n*th last

Since barbarisms like 1th and 3th are barbaric, synonyms like 1st and 3rd are accepted as well.

Variables

The built-in variables and their default values are:

```
boxwid 0.75                boxht 0.5
circlerad 0.25             arcrad 0.25
ellipsewid 0.75            ellipseht 0.5
linewid 0.5                lineht 0.5
movewid 0.5                moveht 0.5
textwid 0                  textht 0
arrowwid 0.05              arrowht 0.1
dashwid 0.1                arrowhead 2
maxpsht 8.5                maxpswid 11
scale 1                    fillval .3
```

These may be changed at any time, and the new values remain in force from picture to picture until changed again or reset by a reset statement. Variables changed within [and] revert to their previous value upon exit from the block. Dimensions are divided by scale during output.

Expressions

Expressions in *pic* are evaluated in floating point. All numbers representing dimensions are taken to be in inches.

expr:

expr op expr
- *expr*
! *expr*
(*expr*)
variable
number
place .x
place .y
place .ht
place .wid
place .rad
sin(*expr*) cos(*expr*) atan2(*expr*,*expr*) log(*expr*) exp(*expr*)
sqrt(*expr*) max(*expr*,*expr*) min(*expr*,*expr*) int(*expr*) rand()

op:

\+ - * / % ^
< <= > >= == != && ||

Definitions

The define and undef statements are not part of the grammar.

define:

define *name* { *replacement text* }

undef:

undef *name*

Occurrences of $1, $2, etc., in the replacement text will be replaced by the corresponding arguments if *name* is invoked as

name(*arg1*, *arg2*, ...)

Non-existent arguments are replaced by null strings. *Replacement text* may contain newlines. The undef statement removes the definition of a macro.

The .PS and .PE Macros

This is the default definition of the .PS and .PE macros:

```
.de PS \" start picture; $1 is height, $2 is width, in inches
.sp .3
.in (\\n(.lu-\\$2)/2u
.ne \\$1
..
.de PE \" end of picture
.in
.sp .6
..
```

Summary of Features Added Since Original Version

The built-in functions sin, cos, atan2, log, exp, sqrt, max, min, int, and rand are available.

The copy statement includes data from a file or that follows immediately:

```
copy "filename"
copy thru macro
copy "filename" thru macro
```

The *macro* may be either the name of a defined macro, or the body of a macro enclosed in braces. If no filename is given, copy copies the input until the next .PE.

The for and if statements provide loops and decision-making:

```
for var=expr to expr by expr do { anything }
if expr then { anything } else { anything }
```

The `by` and `else` clauses are optional. The *expr* in an `if` may use the usual relational operators or the tests *str1* `==` (or `!=`) *str2* for two quoted strings.

The `sh` command executes any sequence of commands, after expanding any defined names:

```
sh { anything }
```

In all of the above, any single character that does not occur within the body may be used to enclose a body, instead of braces, as in

```
define name X replacement text X
```

Text strings are first-class citizens: a statement beginning with a sequence of text strings is treated as an invisible box with the strings positioned at its center. The variable `textht` and `textwid` may be set to any values to control positioning. The height of *n* such strings is *n* × `textht`.

It is possible to convert expressions to formatted strings:

```
sprintf("format", expr, expr, ...)
```

is equivalent to a quoted string in any context. Variants of `%f` and `%g` are the only sensible format conversions.

Built-in variables may be reset to default values with `reset`.

The `undef` statement removes a macro definition.

Arrowheads may be filled with the `arrowhead` variable; their positioning is improved on arcs.

The width and height of the generated picture may be set independently from the `.PS` line; the maximum height and width are set from `maxpsht` and `maxpswid`.

The state of *troff*'s fill or no-fill mode is preserved around a picture.

Input numbers may be expressed in `E` notation.

Numerous internal changes have been made as well. Any number of objects, text strings, etc., may be used; the only limit is total available memory. Output is now produced in inches instead of units for a particular typesetter, so the `-T` option has gone away.